Neural Science for Engineers
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Lecture - 33
Brain regions and associated functions

Hi, in our previous classes we discussed the how skeletal muscle function happens and I started out with individual muscle cells, the local control mechanisms, then stepped up gradually to segmental level control, inter segmental level control and spinal cord level control.

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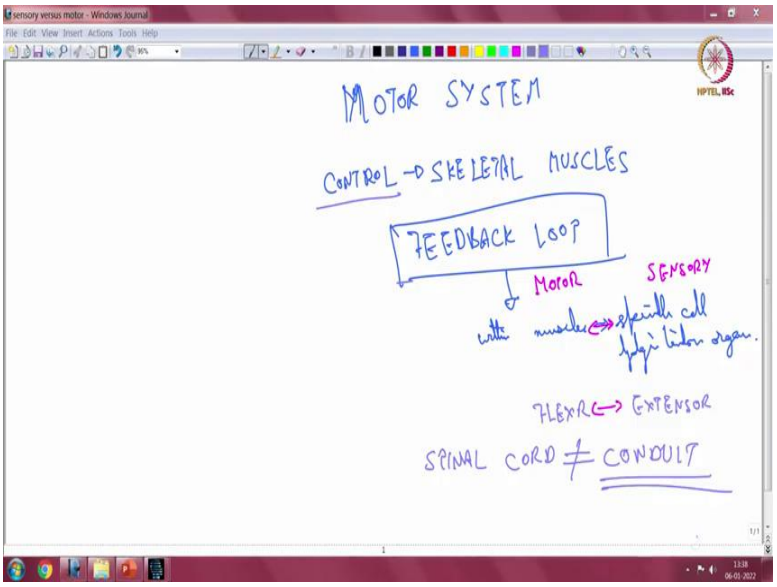

So, the motor system which is basically what I was discussing in various fashions, that is different parts of it, the anatomy of it, how things are from the spinal cord, brain, how they function in very broad terms was described. Now, what actually I was trying to describe is control of skeletal muscles as such. Now, when I use control there are several mechanisms which have to be kept in mind.

So, one common theme which is there is the feedback loop. Now, it is important to know that the feedback loop exists within muscles; example is the spindle cell, the Golgi tendon organ and several other kinds of receptors. So, these are basically within the muscles and then you have got the muscle interacts with the spindle cells which are sensory.

So, this is the sensory part, this is the motor part. Now, you also have instances in which flexor muscles interact with extensor muscles. So, that is another kind of loop. So, when the flexes are acting you would generally expect extensor to go down and vice versa. So, when the extensor acting flexes do not act there are exceptions rule, as you can imagine that the kind of varied kinds of movements you would do every minute, second cannot be encompassed within very strict rigid rules.

And as in all biological systems they are very fluid, they are very analog, and their control mechanisms are equally fluid. So, that is the reason I highlighted the term control in the context of this feedback loops. Now, there is also this idea that the spinal cord is not a conduit. So, what I mean is you would in the anatomical discussions we had several times several classes earlier.

You would imagine that the spinal cord is just a pathway through which these fibers cables go through from the brain to the peripheral muscles and back from the sense organs to the brain and it just it is just about that, but you can understand that there is a lot of control mechanisms which are in the spinal cord. And these are, so you would look at it as a hierarchy of control systems, control systems which are you know they are not centralized, they are distributed control system. So, that is I think a keyword.

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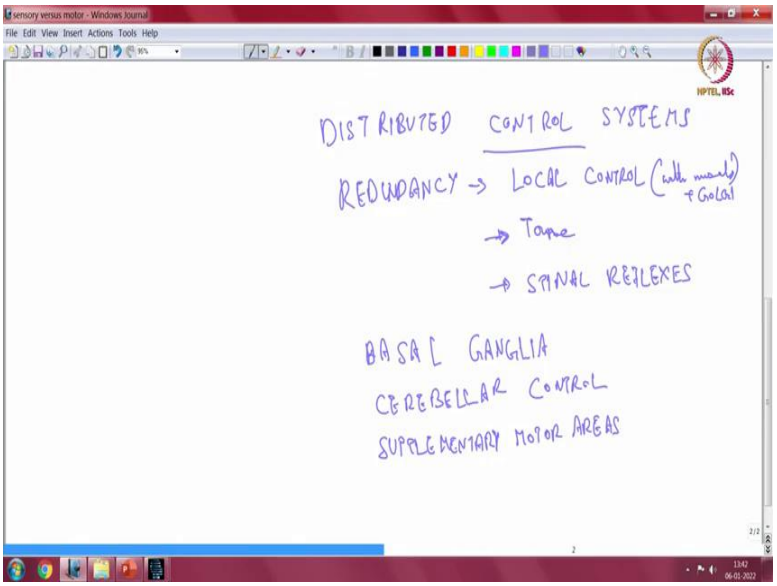

So, you have distributed control systems, so you have control systems which are spanning locally say within the muscle you have this control system which say prevents

the muscle from being too much activated or too less activated, that is the phenomenon of tone. And how I told you that tone is modulated, and the gain control is actually what the top-level stuff does. So, the spinal cord takes care of the rest of the simpler calculations.

You also looked at redundancy. So, redundancy in the local control that is within muscle. We spoke about tone which is in incidentally another mechanism of control, it is a different thing altogether in biological terms, but ultimately what tone does is in regulating movement and regulating posture, regulating the control itself.

So, tone, so tone is another issue which we discussed and the this is a different thing. So, muscle spindle is, muscle spindle plus Golgi is one thing. So, we discussed about tone and then there are spinal reflexes. So, we see that you know there are so many checks and balances for every single moment, there is a lot of data which is generated for every single moment and that is carried forth, most of it is locally processed it, you know it is not carried upwards all the way to the cortex.

So, the cortex does not bother about what is the current, of course it does know about the current state of tone in a very high level sense of the term, but it does not know many of the minute to second to second or millisecond to millisecond changes which happen, those things are regulated at the spinal cord level and then I told about these spinal reflexes.

Now, why this is important is because when we are discussing control, we also have the idea that there are several other structures within the brain which are responsible for control of movements. So, there is something called basal ganglia which we have discussed earlier, we have cerebellar control, and we also have something called supplementary motor areas.

So, these have, these are again you know higher level control systems which are built at various parts, you can imagine that the part of the brain itself is devoted to the control of movement. And if you recollect the discussion which I had in the cerebellum, cerebellum is responsible not only for fluent speech the even for generating fluid movement and yeah you know any movement.

So, when we use the term motor it also includes speech, speech is basically muscle action modulating the flow of air across the lungs to the outside, so that is speech. So, speech is modulated controlled by the cerebellum then you have a basal ganglia which do so many things and again is responsible for generating movements and the fluidity of movements and supplementary motor areas.

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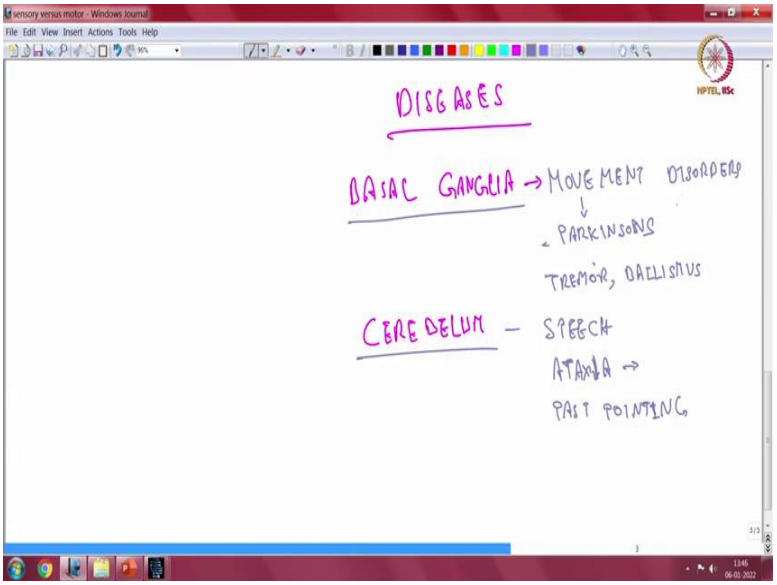

Now, how do we know such kind of things? So, each of these the relevant roles are understood when we look at the diseases which affect these systems. So, why they exist? Why there is so much of redundancy built is something which is very difficult to answer.

At least I have no idea of the answer, you may think say in if you look at in general manmade systems you have redundant systems and hyper redundant systems which may have 1 or 2 or some 3, 4 overlapping servo mechanisms which look at checks and balances within a system. But here we are looking at, we are looking at a design in which there are various things which are controlled at various levels.

If you ask me as a physician biologist what exactly ultimately all of them perform the same role the basal ganglia is involved in the control of movement. Cerebellum is involved in the control of movement, the spinal cord reflexes control movement, the cortex sort of generates movements, the basal ganglia cerebellum modulate movement and supplementary motor area is also involving involved in the modulation of movement.

But if you look at diseases, they are pretty different. So, when you have basal ganglia disorders, you patient ends up with this with set of diseases which are classified as movement disorders. So, this is something like Parkinson's disease, I think many people would be familiar with, then Parkinson's then there are so many varieties of that, but basically this movements can be classified as tremor ballismus and this one more ballismus and something else which I forget.

Anyway, the point is not to teach you medicine, the point is that there are very distinct manifestations of diseases within this specific structure. So, they are not they are not overlapping, they are not they are not redundant in the sense that you take out one of those systems the other system takes over. Each system controls a specific act of the muscle activity and that is the that is the point.

If you look at cerebellum, you have varied kind of symptoms which can be with speech, then ataxia which is loss of balance basically, you are not able to maintain posture and then there are varied manifestations like what is that past pointing, so these are examples. So, there are varied kinds of diseases say spinocerebellar diseases, para cerebellar diseases, acoustic schwannoma in our practice which cause cerebellar dysfunction.

So, there are varied kinds of tumors other neurological diseases which affect the cerebellum, and they manifest very differently. See remember there are issues in speech even in basal ganglia diseases, by patients with Parkinson's have significant speech output, they have characteristic handwriting changes such as micrographia those are entities.

So, they all manifest differently. So, you would not confuse a basal ganglia disorder with cerebellar disorder and vice versa, though both of them are looking at different aspects of muscle function and control. So, that is the idea that we are looking at very distributed control systems and I do not know a term which can encompass the amount of redundancy which is built into the system.

So, though it is that one neuron just acts on a skeleton muscle and produces a contraction, it is a very simplified view of the world, but of the concept, but the world view of it is pretty complex. So, that is how things are the things are in the biological side of servo control systems. So, from here I would go into those issues a little later and

we will look at control systems at a later point of time, because they are separate topics, I would discuss that in some length after some duration of time.

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So, we progress on to the sensory system and in the sensory system I would start with vision. Why I start with vision and with none other things is that this is reiterating that it is a course for a basically for engineering faculty students and people who are interested in varied kinds of engineering.

And if you look at one single biological system which has inspired a lot of engineering spin offs is the vision. Now, of course, all of us are aware of the camera, the camera is thought sort of theoretically modeled on the eye. So, that is one of the older inventions, but we understand that almost everybody nowadays has a camera in her or his pocket, it is a it is the most ubiquitous you know manifest of biological entity.

So, when we speak about vision it is it encompasses a lot of things and I think I will take a diversion here to speak something about teaching methods which I have adopted during this course. So, I have tried various techniques, for somebody who is been following the entire course and not jumping across lectures you would notice that a lot of different techniques have been used. Primarily I have been very insistent upon using a blackboard or whiteboard approach in which I write stuff and talk to you directly.

It is nice for some students, may not be nice for some students. Some students may not, I will start with the not liking part of it and not liking part of it is there are no there are no pictures which you can capture, you know you do not have a key slide you do not have a keynote at every single point in the discussion which you can capture. But incidentally the course was not meant for such a kind of, you know it is not an exam-oriented course in which you would in your career face questions from these topics.

So, this topic was meant for people who want a greater understanding of the neurosciences in general and specifically because the work relates to something in neurosciences. So, coming, so I try to avoid slides that is the point. So, instead of showing a slide and trying to explain the slide, the contents of the slide I use the free hands on, but there is nothing which prevents me from using slides. There are some issues with using slides because material basically graphic material is copyrighted, and it needs to be acknowledged.

So, instead of using acknowledgement at every single level, I have I already quoted Principles of Neuroscience is the reference textbook for you, please use the textbook. The other reason of dragging in the textbook and teaching methodology here is that so far, the course has been independent, say you do not bother to open your textbook, do not bother to check Kandel and Schwartz.

You still can figure out most of the stuff just listening to the lectures, to the point of understanding and maybe even to the point of you know point of writing exams based on the course and even further on. The issue there is that this is not what I understand of an American style of teaching in which there is a lot of homework, and the teacher guides you through one set of concepts to another set of concepts and leave you to work out the rest.

But this is a topic, vision is a topic in which I would want you to look at the reference book, please go through the chapters they might be a bit difficult to digest. But the methodology I have open adopted here is the American style in which I introduce concepts and people who are interested should go greater into that. It is also an insurance from my side because many of the topics which I am about to discuss, I do acknowledge that I have fairly limited knowledge on not that I have extensive knowledge on the stuff which I have told earlier.

Most of that is from my own understanding of medical this one, how what I have been taught by my teachers and what I have read from books. But this is a topic in which people of very divergent backgrounds who are interested in this please go back and read the book after you have listened to this class. It would be difficult for you to meander through that couple of chapters on vision in Kandel.

Because a bit, what do you say maybe a bit difficult for people who are not from a biological background, it is fairly strictly for biological student consumption. So, when we the another; the other reason is they got a beautiful introduction on the philosophical basis of vision which I do not think I can parrot out here because my memory fails me in using the language used by the authors in describing the introducing the concept.

So, having said that we start with our topic so, vision computer vision as a hot favourite, cameras are there with all of us and if you anybody who is in the ML, AI space also recognized that CNNs, the Convoluted Neural Networks have extensive philosophical connects with the human visual system. And surprisingly although only very basic concepts have been implemented, the results which have come out have are very similar to what we know of human vision and animal higher animal vision.

So, this is a place where the reason I place where I have to again highlight the fact that you need to go back to the textbooks, especially for those people who are dealing with CNNs, because there are many people who would be using going on to more complicated convolutional networks or somebody who is wanting to design a convolutional network specific for a particular task.

And take inspiration from biology there are so much of things which have been discovered in the biological sciences, but which may find relevant role in implementing neural network-based architectures. Architectures I say because these are very complex systems.

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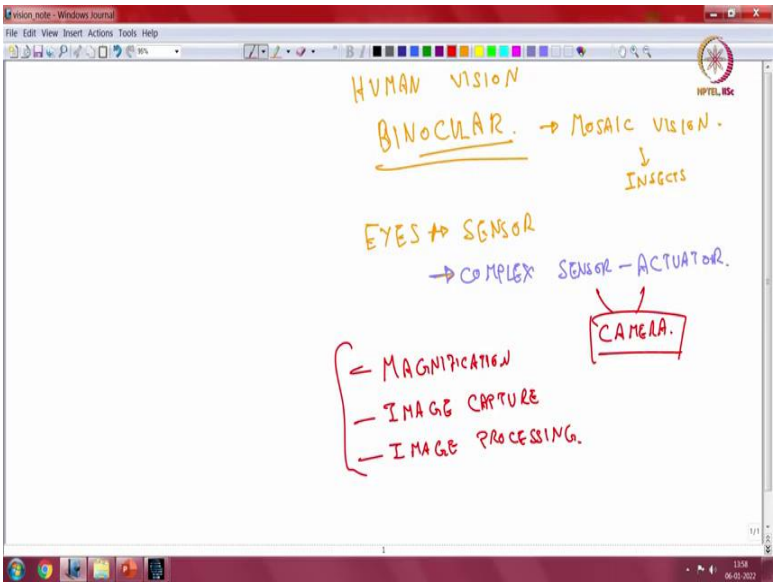

So, allow me to allow me to discuss vision in some way. So, we are binocular human vision. So, when I use binocular if you would ask whether there are monocular or binocular is 2 eyes by the way, binocular and there is this mosaic vision in insects and there are very interesting photoreceptive systems, I think vision would confine yeah the discussion to a great extent.

So, there are varied kinds of vision systems, and we have binocular and both of them are in they look ahead, there are animals in which we have wider fields of vision with relevant issues. Anyway, I do not think I am competent enough to discuss that level of detail.

So, we start with the binocular part of the story, so which basically means that we have eyes. Now eyes, eyes are not just for the sensor part of the system, they are not just sensor, they are not just sensor what I mean to say is it is a complex sensor actuator sort of like a camera, sort of like a camera. So, camera basically ok if you look at what a camera does is you got a magnification, image capture, and image processing.

If you look at any mobile cameras, I think all these parts are there and I will try to make link between these various parts which are there within the visual system. See remember I am not discussing just the eye. So, eyes as such is the end sensor part of the story, within the eye is located the photoreceptor complexes and then yeah. So, what are the parts of the visual system?

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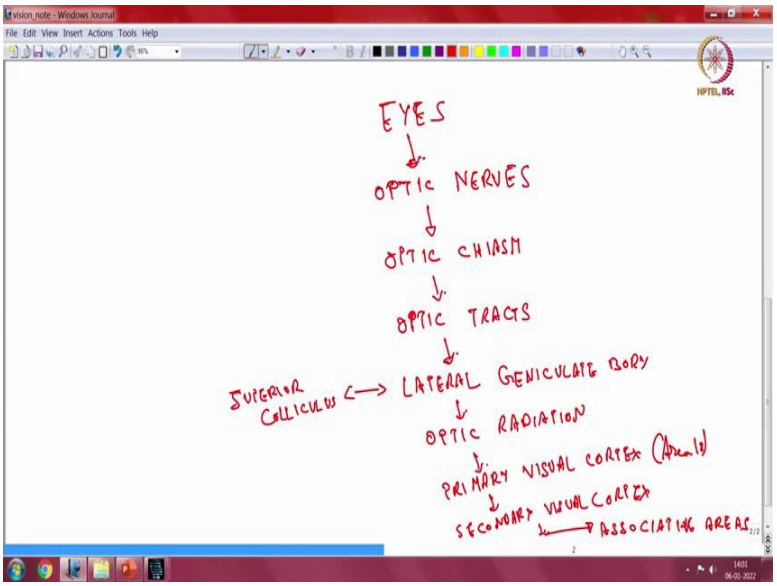

So, eyes then they go on to the optic nerves, terminology is important because the subsequent discussion would require you that you understand these things little bit, optic chiasm, then you got optic tracts, the lateral geniculate body. Sort of connected to the superior colliculus, I hope these terms look familiar because these are terms which I have in some fashion introduced you during the discussion on brain anatomy at various levels.

I would be discussing again all these things and how to identify these parts within the within an image because they do have some relevance and from there is optic radiation, then primary visual cortex, area 18 secondary visual cortex go on to associate areas which are actually common.

So, this whole stuff, this whole stuff is the visual apparatus, and it is not again going back into the spinal cord discussion, everything is not just conduit you know it is not that the eye is connected to the brain, it is not that simple. So, at each level something happens, some of those things are known to us many of those things are still unknown as to why these things happen, they are there.

And they are there, they have been there consistently across every single human being, and you know it is strictly coded within the genes. So, you know it looks very funny why these things are the way they are, but somewhere in evolution it has been found to be relevant and it has been, it has been carried forward from what from one generation to

another; human, maybe even animal to whatever I understand of animal vision. So, these are the various parts of it I will draw a bad diagram and start with that.

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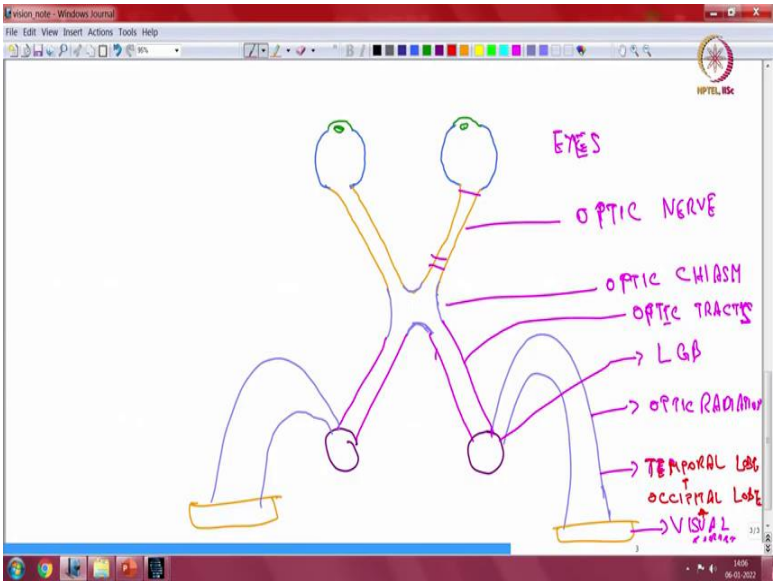

So, I hope it looks sensible, I am bad at drawing which is one of the reasons I have not used many diagrams as such in my discussions. So no, I need green ok. So, that is one eye, this is the second eye, eyes, that is the lens next part of the story is the optic tract which is drawn like this.

Then you got the optic chiasm, which is all of this, then you have the optic tract which should theoretically go to the lateral geniculate body and then you got the radiation schematic diagram. So, you should forgive me for this diagram, but these are to highlight. So, earlier I drew a line diagram which basically illustrates and then you put a stop to this thing and then that should make the cortex. I got limited colors here and I think I have to repeat colors over.

So, I need some more description I think I will get back. So, this is eyes, then this is the optic nerve both of these optic nerves come together and that is called optic chiasm. These two things over here as the optic tracks then this is the Lateral Geniculate Body, short form LGB optic radiation, then you have the visual cortex. So, this constitutes the various parts within the visual apparatus we will deal with relevant parts of this optic apparatus.

None of you are planning to switch careers at this stage, I hope. So, I would not bore you with or teach you stuff which are which I feel may not be required for this audience. So, neuro-surgically, the optic nerve is divided into multiple other places. So, that is how we study the optic nerve and the optic tract itself has so many other parts, radiation is in the this incidentally is in the temporal lobe plus occipistal lobe, and I think the yeah sorry the visual cortex is also in the occipital lobe from whatever discussions we have had so far.

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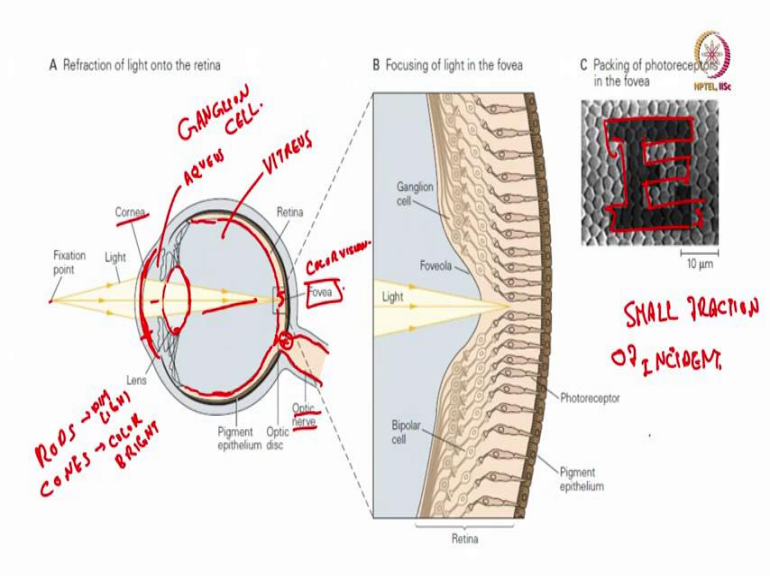

So, a little bit of the eye as such the physical apparatus of the eye that is something which is shown over here, all of you would be familiar with the how would at least some have some idea of how light is processed within the eye. A greater detail is what is necessary. So, we have a magnification system, so magnification system is this black thing which you see in the center of your eye is the cornea. So, this is the cornea and yeah this is single color because it is power point.

And this structure here is the lens. So, both of them have magnifying property convex lens system two convex lens systems, the fixation point from the light from fixation point converges to a single point within the fovea. The fovea is cited directly behind these behind the long axis of the lens system and that area is what is responsible for collaboration.

Most of what we see, please note that you can see this gentle curvature over here. So, you have not only a magnifying system which is curved, but you also have a receptor

system, sensor system which is curved which is fairly I think different from photoreceptors light sensors which are implemented in cameras of varying kind. Incidentally something which is similar to this is radio telescopes in which they have disk shaped things.

But that the principles might be different, it is different. So, the rest of the area over here is the retina, yellow in color I am just drawing it for completeness' sake. So, that whole thing constitutes a retina, I hope people would have heard about rods and cones and they are the photoreceptors.

So, rods and cones, we will discuss this in a slum some detail in later classes, more it serves two purposes one has to understand what is happening. It is also into contrast with several topics which I have had in my introductory classes on action potential synapses etcetera, etcetera. So, rods and cones, rods are for dim light, cones is for color vision and bright light.

So, the optic nerve, so all the receptors at after some kind of several synapses in between join together, and the output of the retina is something called as ganglion cell. So, these ganglion cells join together and form the optic nerve, optic nerve is this one. The place where it exits out is the optic disc and that is a place where there is no, there is no there are no photoreceptors in the optic disc, there is the blind spot again I presume most people would have heard about the blind spot.

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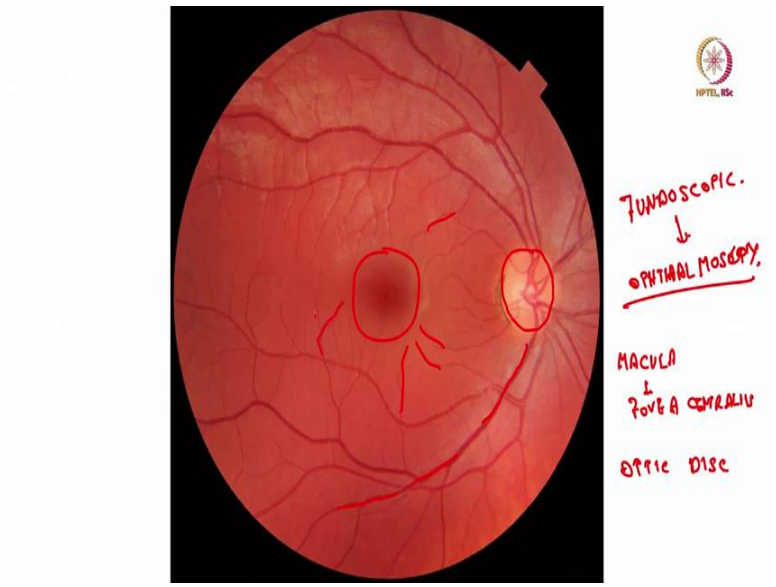

So, we go on to the next slide, this is how the eye looks in with when you do an ophthalmic examination. So, the retina looks somewhat like this, I put this picture so that you have some context to the picture diagrams which are there. This is again taken from Wikipedia and not taken it from any patient data. So, you get an image like this when you undergo a fundoscopic examination, fundoscopic examination which is examination of your eye using a lens of ophthalmoscopy.

So, ophthalmoscopy is the technique by which you do you check the fundus and it is the most accessible part of the vessel system of a human being and you can derive several. I think again people who are interested can check up varying kind of eye diseases, other diseases such as diabetes, hypertension which can be changes of which can be seen within the fundoscopic picture.

So, when I told you that when you look in the long axis of the visual apparatus, long axis is the center of the cornea, and the center of the lens goes back to this dark area which is called as the macula. This would form the macula, macula and fovea sit is also called fovea centralis, everything starts at this area which is the blind spot which is the optic disc.

So, that gives you a brief understanding, you can see these red things are the blood vessels which are traversing the retinal system, please do note that it is traversing the receptor system and sort of occluding the receptor system, but again vision is a very energy intensive activity, and a lot of blood is required for sustaining the activity.

Now, if you look at one very prominent feature over here is the central part is getting fed by all these vessels and in general there is nothing traversing from the optic disc across. So, that is to ensure that there is high fidelity of vision, which is required, you know the body acknowledges that superior quality of superior quality of vision requires that nothing travels across its receptor system.

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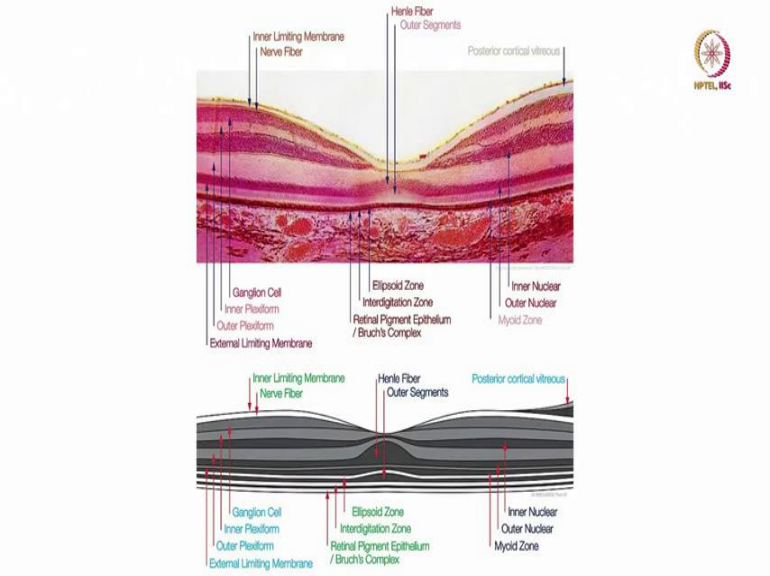

A little bit on this is a bigger magnified view, these are medical terminologies which you would not need to know in a greater detail, I think I have to mention. So, there is this fluid. So, there is something called aqueous humor here which is liquid and then vitreous which is again transparent, but it is a colloid material.

So, there are various media within the eye through which this the light has to pass before it be before it being taken up by the photoreceptor system. So, this is how it would look on microscopy, the phobia which is the depression over here and the various parts which are noted within here.

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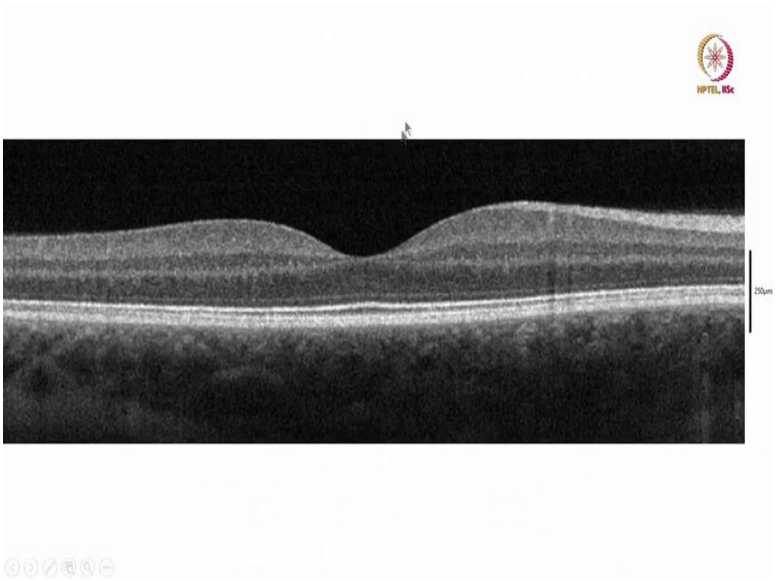

Again, I think this is an electron microscopic view, you would get images like this or not electron microscopy even an OCT or ocular computerized tomography would give you some image like this.

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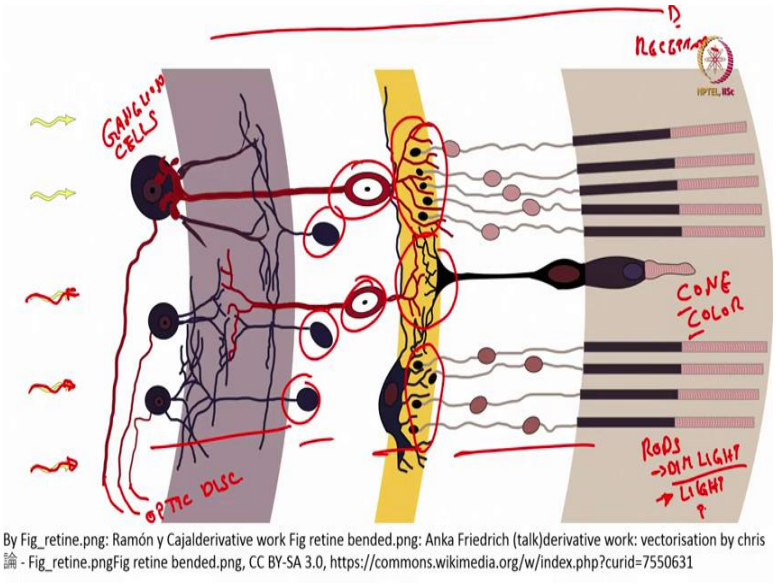

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So, this is a magnified view of the same and we are looking at the most inefficient sensor system ever designed. So, we are looking at a sensor system which is taking in photons, reacting to photons capturing the data stored within the photons, it is not the energy remember, it is the data which is stored from the photons.

Process it and send it and anybody would understand that vision is the major way in which human beings interact with the environment, vision is responsible for most of the communication which we do in terms of reading viewing anything text, videos, the environment everything.

But surprisingly light when it has to enter into the optic apparatus has to go through all of these layers. So, this is the receptor part of this story. So, the receptors are the this is a cone, these are rods. So, rods look like that, and cones look like that, cone is for color and rods are for dim light and are sort of not exactly chromatic I would not call it a chromatic I have a different light I think light perception due to in light sensitivity is better in dim light.

So, again, unlike conventional sensor design for vision computer vision, please note that the sensor system has several other kinds of cells, and these cells are synapsing with the rods and cones in varying layers, and these are distinct layers which are observed observable consistently across retinas.

So, each of these cells are fairly specific, they look specific, and they have different names. The final output in turn goes to these bigger cells which are the ganglion cells which I have already spoke about. So, these ganglion cells in turn go out through the optic disc.

So, optic disc is forming the optic now, so you can easily imagine that the why the blind spot exists. For these nerves from to converge from all directions and then go into the optic nerve, you would have an area where there are no photoreceptors and that is the idea. So, this is the this is the general story of the story of the eye, how light is taken from outside through the cornea, the aqueus humor, the lens.

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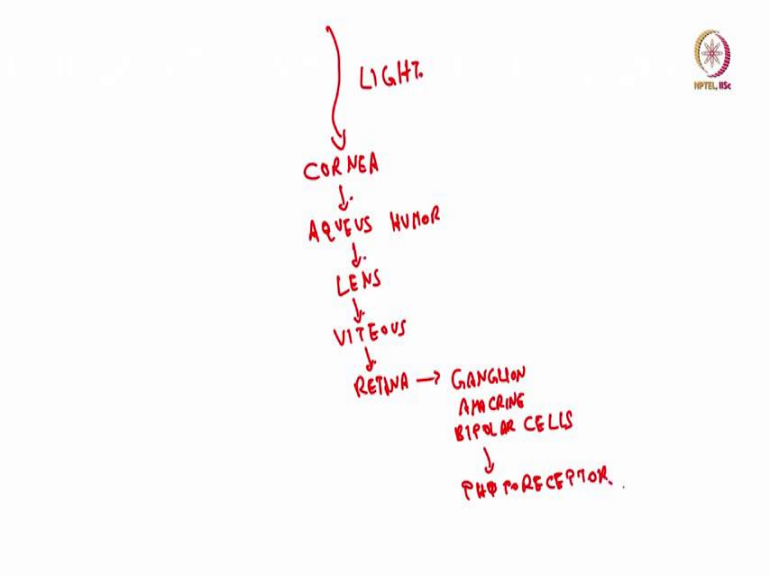

Cornea as the outer part, aqueus humor, lens, vitreous, retina, and that traverses through so many layers ganglion, amacrine, bipolar cells to photoreceptor.

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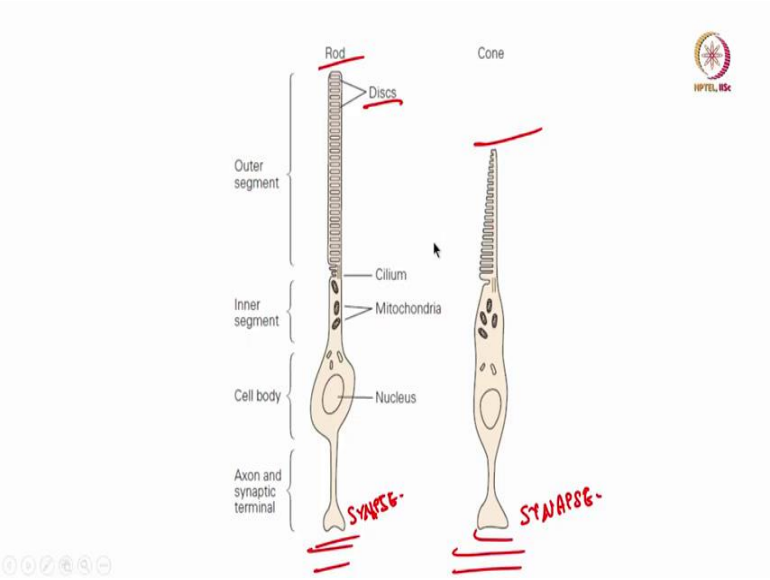

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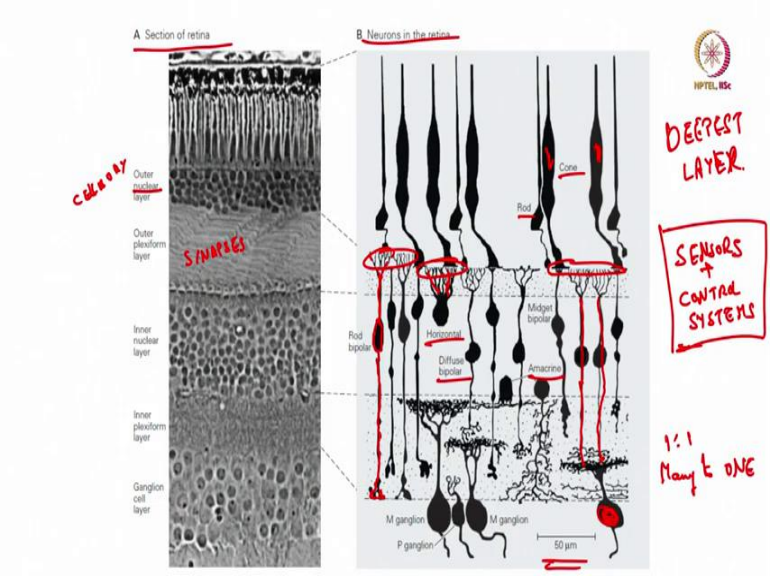

So, this is how the retina looks like. So, the this is a more organized diagram than the one which I showed, and this is the cross section of the retina in actual terms, and this is the neurons within the retina. So, the deepest layer is the rod and cones and after that you have this rod bipolar cells which are bipolar because they have got one set of processes which are over here and another set of processes, bipolar is 2 poles.

So, there is another set of poles over here, horizontal because they are connecting only in this layer. So, these layers have different names, the nuclear layer is these cell bodies of this nuclear is to cell body cell bodies of the rods and cones, plexiform layers is for the synapses in a nuclear layer is the horizontal bipolar, horizontal bipolar amacrine cells. So, these are the kinds of cells which are in between and then they go to varying kinds of ganglion cells.

So, please note that the ganglion cells do not have 1 is to 1, they are many to 1. Why many to 1? You can find this bipolar coming over here. So, bipolar-bipolar comes over here and synapses to this ganglion. There is one more bipolar coming over here and synapses to this ganglion. So, one ganglion cell takes in data from multiple data sources and that is something which is necessary to be remembered.

So, 60; 50 microns so this is in this is to find if we feel the bridge between the medical side of the story, the physiology side of the story and the architecture side of the story. So, different layers contain different things the diseases which affect each layer are

different and they have that kind of importance. In terms of functional importance, you should remember that the receptor systems are the deepest layer. There is something else, some basal membrane over there, but we are not going to look at that, we are looking only at the functional aspects over here.

So, these connections are important. So, how these connections happen as a lot and lot to lot of relevance to the subsequent thing? Again, the principle which is followed is the same that you have, sensors plus control systems built into each other, they are complex. They you do not have separate you know they are not separate photoreceptors which is taken electronically to or to the next level and processing is done.

It is that these are inbuilt. In fact, in the in a shorter while I will be discussing how it is important, even in the notion of capturing data. So, little more detail, I think we should know something about these entities, and they have been they have been responsible for quite some Nobel Prizes which you can look at and they are important.

So, there are these discs, and this is a rod and mitochondria nucleus and then there is a synapse. So, there are changes in, differences in length, there are changes in the way yeah how the way of course, we will be discussing subsequently, but the structure itself is pretty different and yet as it similar like in several biological entities.

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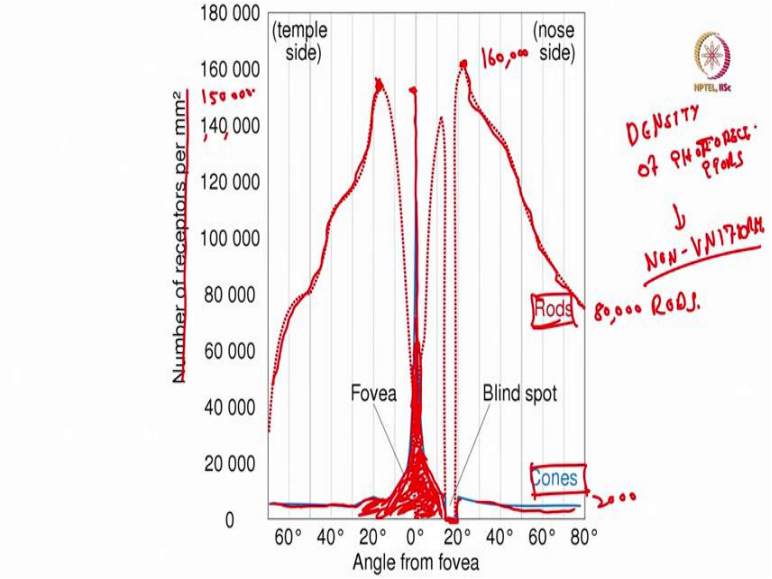

So, it is important to remember that the density of photoreceptors non-uniform. So, look at this diagram and we will start with the blind spot. So, blind spot no photoreceptor and this is the rods red in rods. So, outside of the, outside of the fovea; fovea is the point which is behind right behind the direct point on the long axis of the eye.

So, rod concentration increases as we come towards the center from the periphery, and it is the same on both the sides. So, concentration of rods increases as we go on to from periphery to center and if you look at for the cones, it is the other way around. So, there is a low concentration of cones in the periphery. Low concentration of cones in the periphery, again dropping to 0 within the blind spot, but then you can notice that in the foveal region there is a high concentration of rods, concentration of cones.

So, that is the sort of significance which I was trying to. So, non-uniform is a very important term for several issues. So, majority of the collaboration is what happens; so, most of our vision is actually what actually happens within the fovea. So, this is the area where there is which is used for vision, the periphery is used in the dark when there is not enough light to activate this color receptors, they have different activation parameters governed by several kinds of laws.

Please do read up if you are interested in that as to how laws manage the activation of these various receptors. So, this is number of receptors per millimeter cube. So, we if you look at peak within the center of the it is around 140,000; 1,40,000 receptors 150 it is, 150,000 within the center of the fovea. Density increases on the either side of the rods to 160 somewhere and it is about 20, less than 20000, 2000 in the periphery for cones and around 80000 for rods.

So, that is the; that is the entire this one is to showcase an important fact that the receptor density is non uniform, the kind of information which is captured is different at various parts of the eye. So, unlike in a camera in which you know you we are very greedy, you capture all the light which is available and try to capture it in shorter durations of time.

The eye does not seem to follow that logic; it captures light different intensities of light at and uses different parts, physical parts of the parts of the retina to process the data. So, that is a important difference. To give you an example if you look at new newer technologies in camera development, you know you have cameras which are very

specific for dark dim light, you have camera technology which is different for bright light.

And there is a lot of post processing techniques, software, and even maybe hardware methodologies which I used to enhance you know if it is too bright a light you need to cut down the light features of the features of light. Not features, parameters of light. Then if it is too dim you enhance things. So, the eye ensures that there is hardware which is built into its system, and it takes care of both dim wide angles and colored light versus dim light.

I am use I, do not you like the term uncolored light because when it is dim it is just that the receptors are not the light is not sufficient enough to activate the receptor. So, you got lower threshold receptors which do not actually detect color, but they are able to perceive so many other things and that is how we have night vision and dim vision.

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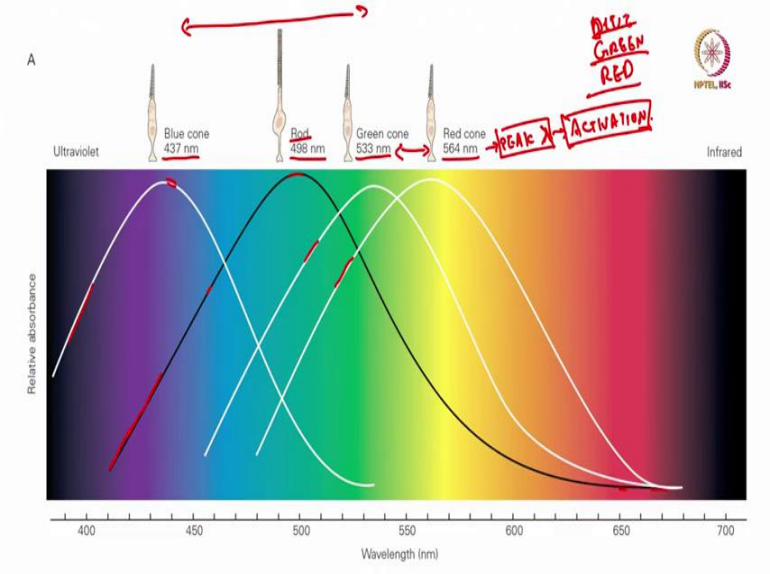

So, we delve a little more into these ideas and we have some derivations which we need to make over here. So, this is the visible spectrum of light and as you see, there are different kinds of rods sorry, different kinds of cones and each different kind of cone is responsible for taking in data from different light wavelengths.

So, there are three blue, green, and red and these are the kinds of cones which are present and if you look at rods there is a single kind of rod which has got a peak absorption at

498 nanometers, blue cone has 437, green cone has 533 and red cone has 564. Now having said that these are not, you know there is some there are some subtleties in the whole story.

So, these are peak, peak wavelengths; so peak wavelengths at which there is maximum activation. Now, I use the term activation because it does not mean that they are sensitive only those to those color this one and as any good sensor, they have a range. So, we will start with the rod range which you can see is this one and it has a very broad range, it covers almost the entire spectrum of visible light.

And from ranging from just below the infrared to below somewhere going sort of into the sort of into the ultraviolet, the blue similarly has a fairly long spectrum fairly broad spectrum and these two are overlapping. So, there is the distance between the green and the red is shorter than the distance between the blue and the green, red combination.

So, remember I started with how things are different from a camera, and this is the second point of difference. So, the first point of not first this is of the third or fourth. So, the first points of differences are that the mechanism of capture involves protein structures, liquid structures, solid structures, through cornea is a membrane. So, you have a lattice membrane which takes in light, the aqueous swimmer as liquid its refractive index very similar to water.

And then you have lens which is actually semi solid, you know it changes its shape and that is one of the mechanisms by which you can which you can see distant and near objects; lenses of particular interest because you should understand that it is a flexible lens. So, it can change its shape and like any biological systems I do not think the lens changes in a linear fashion.

So, you have a non-linear lens system controlled by muscles, which ensure that you can seamlessly see across anything from the marking on the pen to the camera which I am viewing at a distance right now. So, that is the kind of scope which the lens gives, we will see other mechanisms which are there in subsequent this one. So, then behind the lens is the vitreous which is again semi it is a clear colloid.

And then you have the various nerve fibers, nerve fibers is fat so and then you got the various cells and at the bottom of the entire apparatus is the receptors. So, light passes

through varying entities with differing refractive indexes and then finally, comes to the end of it only to find, only to find that the receptor complex is equally crazy.

So, you have a receptor complex which is asymmetric in its distribution, spatial distribution, which is curved in itself. So, you would imagine that you would need a planar, planar receptive surface for light to come and then form a steady image on the retina. But here we look at we understand that the image which would form is always a curved image, curved image of a globe of a you know is the inverse representation of the world.

So, hello world in eye is a curved world, so curved world in the eye. Now, that is in the fovea and the rest of it is also it is got a different curvature. So, you have a fovea which is a different, which is a different curvature and the retina, which is a different curvature, and within the retina itself you note that the distribution of the density of the rods and cones is so non-uniform.

So, we have high density within the center differing lesser intensity, that is the that is the how much the 6th or 7th difference, then on top of that you have this receptor complexes in the light for RGB fans yeah. So, this is yeah this is RGB still. So, the channels remain the same, but you can note that the sensitivity of the channels are different.

So, you have got a green and red which is towards one part of the story and then you have a blue cone which takes up another part of the spectrum and there is a sort of a gap in between in which the rods take up a lot of data. So, there is asymmetry, there is non-linearity I think that is the correct term.

So, we are looking at a completely non-linear system starting from the time light enters into the eye and even the entry of the light of course, is variable you have first of all you have the eyelashes which to some extent protects changes, I would not say protects it changes the kind of the quality of light which enters into your eye. And then you have the pupil which changes its diameter, and which also changes the amount of light which reaches to the system.

So, there it is a compact again sensor actuator system compact complex, I do not know whether to call it redundant because you know it looks almost like the eyes it is a it is a maybe it is a local minima in a evolutionary scale, it is not perfect because of all these

imperfections which I told which should I am pretty sure as any engineer would agree that it is a very incomplete system.

A system which is asymmetric non-linear, and you know and sort of poorly designed, the poor design part of it as an explanation. Poor design part of the explanation is that the sensor systems have the highest oxygen requirements and so they are placed at the place where blood vessels can access them easier rather than the other side where blood vessel access is difficult in terms of architectural design.

So, that is the explanation which I found; but in you know what do you trade off? So, we have traded off a lot of light you know, the amount of light which would actually reach each area the flux of light which is incident on a area of the retina where is this, yeah I thought I saw that somewhere. So, this is the amount of light which should enter from a letter E, it is just a fraction.

It is actually a small fraction of incident light, and we comprehend the wall through that. So, there is a drop here, there is a drop here there is a drop here and then there is a drop here and then there is a drop here. So, light you know the input signal, input signal decreases across the entire receptor system, but it is a local minima. So, it is a local minima for evolutionary skills. Where things are had come to an head and it was optimized for whatever reason it is. So, we have got this very deliciously unbalanced system.

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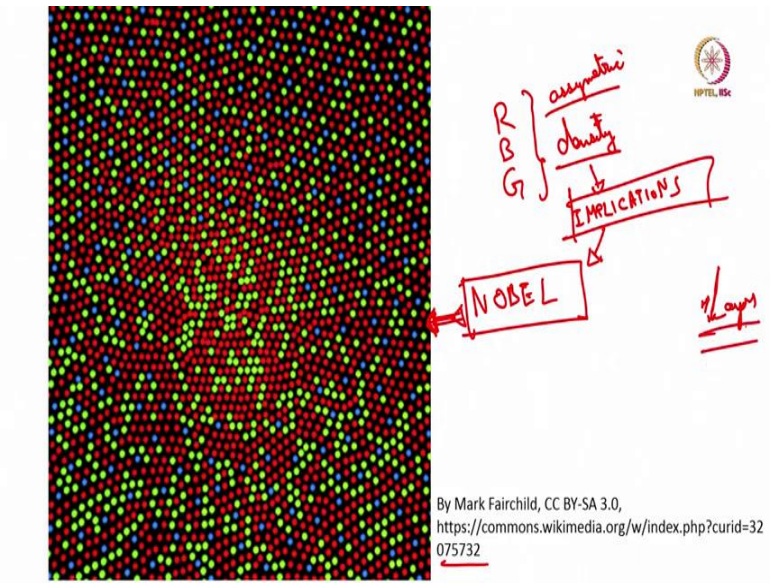

So, with that we come to the next part of the story. So, for all the beauty of color vision you would imagine that the rods and sorry, not the rods are one single nanometer, and you would expect it to be uniformly distributed which in incidentally it is not so. But if you look at cone distributions, if you look at a CNN input or if you look at you know any kind of image processing algorithm in which you got red, blue and green channels, you give equal weightage to these channels and a mixture of RGB per pixel is what gives the information about the image for people who are into the image processing site.

But the picture from Wikipedia, so we got a red, blue and RGB sorry, red, blue, and green cones and one look at the picture the most striking feature is the asymmetry of it. So, the asymmetry of it is a stark feature of retina one of the, you know the nature seems to be bent on adopting non-linearity and analog systems are you know the nature spent a lot of time generating this, it is not that nature is not aware of the digital method.

If you recollect my action potential, the action potential is a very digital method it is a binary system of trans information transfer, very solidly implemented across the nervous system. But look at the retina, the retina is deliciously non-linear, it just not does not form any kind of coherence and that is one of the beauties, you know the beauties of the system in spite of which we are able to comprehend so many things see around ourselves, implement, talk, communicate, understand all the world around us and.

So, there is a Nobel Prize in this, so I will write so far, I have not been able to comprehend a Nobel Prize in any of my lectures so but there is a Nobel Prize in this image. The logic behind this I feel is more than sufficient for a Nobel Prize and it is to this audience that I find it confident in saying that the asymmetric density and its implications should be sufficient enough for a Nobel.

So, layers of asymmetry and non-linearity. So, that is the benchmark which is being followed within the visual system. So, we will take a break over here and then continue a little more into receptor physiology and understand how things are. I am not focusing on that aspect for too much because it would not be of much use to this particular audience. But however, I will try to cover the broader aspects which I am comfortable with, we will continue in the next session.